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EDITOR, C. A. CHANT ASSISTANT EDITOR, F. S. HOGG

David Dunlap Observatory
Richmond Hill P.O., Ont.

ASSOCIATE EDITORS:

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Ottawa

J. A. PEARCE
Head Astronomer
Dominion Astrophysical Observatory
Victoria, B.C.

J. PATTERSON
Controller of the Meteorological Service of Canada, Toronto

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THE JOURNAL
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VOL. XXXIX, NO. 4 APRIL, 1945 WHOLE NO. 343

AN INTRODUCTION TO THE QUANTUM THEORY AND ITS BEARING ON ASTRONOMY*

BY A. F. STEVENSON

1. INTRODUCTION.

THERE are two theories of fundamental importance which distinguish modern physics from what is commonly called "classical physics"—i.e., the physics based on the mechanics of Newton and the electromagnetic theory of Maxwell and his predecessors. These are the theory of relativity and the quantum theory. They have had, and continue to have, a great influence on the development of physics and the allied sciences of chemistry and astronomy.

The quantum theory has never had the same popular appeal as the theory of relativity, which has found its way into the popular press and has even had limericks composed in its honour[1]. This is doubtless due to the fact that the theory of relativity upsets our common-sense ideas of space and time in a way that the quantum theory does not. Nevertheless, the quantum theory occupies at least *as* important a place in the physics of today, and its consequences are just as revolutionary.

In this article, an attempt will be made to give some account of the quantum theory from a non-technical point of view. It is,

[1]The best known of these was composed by a Canadian Professor and runs somewhat as follows:

There was a young lady named Bright,
Whose speed was much faster than light,
She set out one day,
In a relative way
And returned home the previous night!

*Adapted from a lecture before the Toronto Centre of the R.A.S.C.

unfortunately, impossible to treat the subject adequately without considerable advanced mathematics and physics; the most that can be done is to give some general idea of the principles involved.

2. Electromagnetic radiation and spectroscopy

As some of the principal applications of the quantum theory are in the field of spectroscopy, and as the subject of spectra will bulk rather large in our discussion, it may be well first to say a few words about such matters for the benefit of those previously unacquainted with them.

All physicists today are agreed that light, as well as ultra-violet rays, infra-red rays, x-rays, radio waves and some other types of "rays", consist of *electromagnetic radiation*— i.e., all such phenomena can be pictured as the propagation of electric and magnetic forces in the form of "waves" outwards from the source of such radiation—be it a star, an electric light bulb, a radio antenna or other source. If we are in an absolutely dark room and switch on the light, what happens is that the glowing filament of the bulb sets electric and magnetic forces into vibration everywhere in the room. Anything which detects or responds to light, such as our eyes, is simply responding to these electric and magnetic forces. We say that an electromagnetic wave is propagated outwards from the source—the electric light bulb in this case. What happens when we throw a stone into a lake gives some idea of what occurs when we switch on the light, except that the "thing propagated" is the height of the lake above its mean level in the case of the stone, whereas in the case of the electric light it is the electric, or magnetic, force. Moreover, the "velocity of propagation", or speed with which the disturbance travels, is incomparably greater in the case of light than in the case of the waves set up by the stone.

The most familiar type of wave is a "sine wave", which is illustrated in figure 1. In the case of electromagnetic radiation the curve represents, at any instant, the way the electric or magnetic force varies as we move in the direction of propagation—i.e. the direction in which the wave is travelling. This wave must then be regarded as moving along bodily with the velocity of propagation —the velocity of light in our case. Such a wave has a definite

frequency, which is the number of vibrations made per second, and can be characterized either by its frequency or by its *wave-length*, which is the distance from crest to crest (or trough to trough) and is shown in the figure. It is easy to show that wave-length and frequency are connected by the relation

Wave-length times frequency = velocity of propagation

so that as the frequency increases the wave-length diminishes and vice versa[2]. The difference between the various kinds of electromagnetic radiation—light, x-rays, radio and so forth, is simply one of frequency (or wave-length). Radio waves have the lowest frequency (longest wave-length); then, in order of increasing frequency, come infra-red rays, visible light, ultra-violet rays,

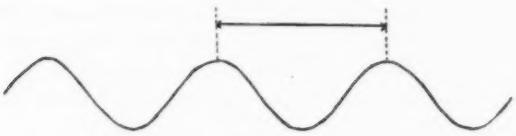


FIG. 1

and so on. There are, of course, continuous gradations within each kind of radiation. Thus we have long and short radio waves, the short waves being used especially for long distance communication, while with visible light the different frequencies correspond to different *colours*.

Radiation need not be of just one single frequency (i.e. a pure sine wave). It can be a superposition or addition, of a number of sine waves of different frequencies. Thus ordinary white light is the superposition of all frequencies within the visible range of frequencies—in other words, white light is really a mixture of light of all shades of colour.

The spectroscope is an instrument which breaks up the radiation emitted by a source into its component frequencies, or, as we say,

[2]This assumes that the velocity of propagation is the same for all frequencies, as is the case with electromagnetic radiation in vacuo. Other cases of wave motion are known, however, where the velocity of propagation varies with the frequency.

gives us the *spectrum* of the radiation[3]. A glass prism which shows the colours of the rainbow when sunlight is viewed through it is a familiar example of a crude kind of spectroscope. The spectrograph does the same thing as the spectroscope, but records the result on a photographic plate so that the spectrum can be studied at leisure and precise measurements of frequency made. It is also possible to measure the *intensity* of the different parts of the spectrum. This is a measure of the energy being carried by the waves of different frequency which go to make up the radiation being analysed, and corresponds roughly, in the case of the visible spectrum, to the brightness.

Spectra may be divided into two types: *continuous spectra*, where *all* frequencies, or all frequencies within certain limits, are present, and *line spectra*, where the radiation is the superposition of a number of *isolated* frequencies. On the photographic plate of the spectrograph a line spectrum consists of a number of dark lines, each line corresponding to a single frequency, whereas in the case of a continuous spectrum there is a general blackening of the plate, or a portion of the plate. In either case, the degree of blackening is a measure of the intensity. Glowing solid bodies emit a continuous spectrum. Gases, on the other hand, usually emit a line spectrum when radiating, though they too may emit continuous spectra if under high pressure.

In addition to the *emission spectrum* discussed above, there is also what is known as an *absorption spectrum*. If radiation which has continuous spectrum is passed through an absorbing medium, part of the radiation is absorbed, resulting in a diminution of the measured intensity. This again may be either continuous absorption or line absorption: the former implying that all frequencies (within, perhaps, certain limits) are subject to absorption, and the latter that absorption occurs only at certain definite isolated, frequencies. Absorption shows itself on the plate of the spectrograph by a relative whiteness, or lack of blackening. A line absorption spectrum thus

[3]In what follows, we shall be concerned primarily with the visible spectrum or the parts of the spectrum adjacent thereto (infra-red and ultra-violet). But the principle that any radiation can be regarded as being a superposition of sine waves of different frequencies applies quite generally.

consists of a number of white lines on a dark background.

To conclude this description of spectrum, it should be remarked that, strictly speaking, a spectrum *line* is also a continuous spectrum, but the range of frequencies involved is so small that for most purposes it can be thought of as consisting of just one single frequency. With very accurate instruments, however, it is possible to actually measure the intensity distribution *within* the line, the "line profile" as it is called.

3. The origin and early development of the quantum theory

With these preliminary remarks, we can consider the origin and development of the quantum theory. It is interesting to note that the theory owed its inception to a single experimental result, namely, the intensity in the different parts of the spectrum emitted by a hot solid body, which is, as already remarked, a continuous spectrum. In general, the spectrum depends on the particular body considered, but there is a standard ideal type of body, known as a "black-body", for which the intensity in the different parts of the spectrum depends only on the *temperature* of the body. This is the simplest to deal with, since a detailed consideration of the constitution of the body does not then arise: all "black bodies" have the same spectrum at the same temperature. The ideal black body is one which absorbs all radiation falling on it; an ordinary black substance does this for radiation in the visible range of frequencies—which is why it appears black—but not for *all* frequencies. Nevertheless, it is possible to reproduce experimentally, by means which we shall not discuss —the ideal "black body radiation".

Now classical physics predicts a certain result for the intensity distribution in the black body radiation, a result known as the Rayleigh-Jeans law (after Rayleigh and Jeans, who were the principal contributors to the subject). But this result does not agree with experiment. Not only does the classical theory predict the wrong result for the intensity distribution, but it predicts that the *total* energy radiated by the black body—adding up the results for all frequencies—should be infinite. This is obviously an absurd result; if such were really the case, it would mean that the radiation received from the most distant star would have sufficient power to

drive every engine on the earth and more! Thus the classical theory breaks down as far as this particular problem is concerned.

In 1900, the celebrated German physicist Max Planck, in seeking to explain theoretically the experimental results relating to black body radiation, showed that a formula for the intensity distribution, which agreed closely in every particular with that found experimentally, could be obtained if the classical theory were modified in one respect.

For our purpose, we can consider that radiating black body to be replaced by an "oscillator". This oscillator may be pictured as an electric charge attached to a spring and performing oscillations with a certain frequency. The oscillating charge then radiates electromagnetic radiation. Of course it is not claimed that a solid body really consists of a charge attached to a spring, but simply that, for our particular purpose—that of discussing the spectrum of black body radiation—we may use this "mathematical model" of a radiating body. Now, according to the classical theory, the *energy* of such an oscillator can have any arbitrary value depending on the magnitude of the oscillation; in particular, the energy has nothing whatever to do with the frequency of the oscillator. Planck, however, assumed that the energy of an oscillator had to be an integral multiple of a certain elementary "quantum" of energy proportional to the frequency. To be precise, Planck assumed that, if the frequency of the oscillator is f,[4] then its energy could be equal to hf, or $2hf$, or $3hf$, and so on, where h is a new universal constant of nature introduced by him, and now known as *Planck's constant*. In the classical theory, on the other hand, it would be taken for granted that the energy of the oscillator could have *any* value; for instance, it might be $1\frac{3}{4}\ hf$. With this new assumption, as already remarked, Planck derived a theoretical formula for intensity in the black body radiation spectrum agreeing very closely with experiment.

To those unacquainted with classical, or Newtonian, mechanics, Planck's assumption may not, perhaps, appear very radical; but to the physicists of the day it seemed extremely revolutionary and

[4]The accepted notation for frequency in physics is the Greek letter ν. The letter f is, however, commonly used by engineers, and we shall employ this as likely to be more familiar.

contrary to all accepted ideas. It would be somewhat as if someone were to come out with the idea that a car can only go at certain speeds which depend on the *colour* of the car, say a yellow car can only travel at 10 or 20 or 30, etc., miles per hour, a blue car at 15 or 30 or 45, etc., miles per hour, and so on. This analogy is inadequate in that in the case of the cars we could, of course, easily measure the speeds of cars and show that the hypothesis is false; whereas in the case of the oscillator of Planck we cannot directly measure its energy, but can only infer it in a very indirect manner. Perhaps, however, it will serve to show the revolutionary character of Planck's hypothesis.

Though physicists were loath to accept Planck's ideas, they gradually gained general recognition. An important contribution to the subject was made by Einstein (of relativity fame) in 1905 who, through a critical consideration of the meaning and consequences of Planck's assumption, was led to propound the idea that eletcromagnetic radiation of a definite frequency f had, at least for some purposes, to be treated as if it consisted of a number of *particles*, the energy of each particle being precisely hf, where h is the aforementioned constant of Planck. These "light particles" are called *photons* or *light quanta*. Thus Einstein extended the "quantum" property, which Planck had previously ascribed to the oscillator, to light itself.

Einstein's hypothesis of photons involves a return, to some extent, to the older "emission theory" of light (Newton), according to which light consisted of a hail of particles. But the photons are not the material things that the older light particles were supposed to be; and for most purposes the classical theory of electromagnetic waves is sufficient. It is only in discussing certain phenomena that the "quantum" property of light is of importance. The two points of view regarding electromagnetic radiation—the "wave" point of view and the "photon" point of view—can be fuzed into a single theory, though the last word on the subject has by no means yet been said; but it is hardly possible to go into this in detail without advanced mathematics.

The photon hypothesis enabled Einstein to explain certain experimental results which the classical theory was powerless to

explain, and it, too, gradually won universal recognition.

4. The Bohr theory

The next great advance in the quantum theory was made by the great Danish physicist Niels Bohr in 1913, an advance which made the theory of fundamental importance in discussing the structure of the atom and the origin of spectra, instead of being confined in its application to a few apparently rather isolated phenomena.

Not long before Bohr's theory came into being, the experiments of Rutherford pointed to the view, universally held today, that the atom, instead of being the hard indivisible thing that it was thought to be before the discovery of the electron, was composed of a central nucleus round which revolved a number of electrons. The atom is thus a kind of miniature solar system, with the nucleus corresponding to the Sun and the electrons to the planets; and the amazing thing about it, from the point of view of the old indivisible atom, is that most of the atom is "empty"; the nucleus and electrons only occupying a very small portion of its total volume.

The question now arises as to the mechanics governing such an atom and as to how it can emit and absorb radiation. The classical theory predicts that the electrons moving in orbits around the nucleus would emit radiation: so far, so good. But it also predicts that, due to this emission of radiation, the electrons would be subject to a kind of frictional force impeding their motion; this would quickly cause them to spiral in to the nucleus and the whole atom thus collapse. Thus the classical theory is powerless to explain even the *existence* of a stable atom. Moreover, even if this frictional force be disregarded, the spectrum of the radiation emitted by an atom cannot be satisfactorily explained on the classical theory.

To account for the facts, Bohr now introduced a very ingenious hypothesis, based on the ideas of Planck and Einstein. He supposed that the atom was capable of existing in a number of "stationary states," each having a definite energy, in which the atom did *not* radiate. He also supposed, however, that it is possible for the atom to "jump" from one stationary state to another of lower energy, at the same time emitting a photon whose energy is equal to the loss of energy by the atom, so that energy is conserved in the process.

The energy of the emitted photon Bohr took to be hf, where h is Planck's constant and f is the frequency of the radiation, in accordance with Einstein's conception of photons. Thus, if the atom is initially in a state of energy E_1 and then jumps down to a state of lower energy E_2, and if f is the frequency of the radiation (photon) emitted, we have

$$E_1 - E_2 = hf.$$

Similarly, absorption is explained by Bohr as follows: if radiation of frequency f, or having f as one of its component frequencies, is incident on an atom, then a photon can be absorbed by the atom. The atom then jumps up to a state of higher energy, the difference in energy again being accounted for by the energy of the photon. Thus the above relation, $E_1 - E_2 = hf$, will hold also for absorption, if E_2 now denotes the energy of the atom in the *initial* stationary state, E_1 the higher energy in the *final* stationary state to which it jumps, and f the frequency of the *absorbed* radiation.

Thus, according to Bohr, the frequencies of the radiation which can be either emitted or absorbed by an atom depend on the possible "energy levels" of the atom,—i.e. the energies in the possible stationary states; and once these energy levels have been calculated, the various possible frequencies can at once be found. Actually, to calculate the energy levels, Bohr and others devised certain mathematical rules. Without going into details, we may say that the motions of the electrons in their orbits round the nucleus and the energies of the atom were calculated as in classical mechanics (but with neglect of the "frictional" force already referred to), but that certain "quantum conditions" were imposed in addition. These quantum conditions have the effect of picking out only certain special electronic orbits as being allowable; when the atom emits or absorbs radiation, the electrons jump from one of these orbits to another.

The only atom for which the calculations can be carried through exactly, on account of mathematical difficulties, is that of hydrogen, which consists of a nucleus and just one single planetary electron. Complete agreement between theory and experiment as to the frequencies of the lines in the hydrogen spectrum is thus obtained[5]—a

[5]Except for certain small refinements, which are explained by means of the new quantum mechanics.

great triumph for the Bohr theory! Other atoms can be handled in many cases approximately, and excellent qualitative agreement between theory and experiment is obtained. Thus, for the first time, Bohr gave a satisfactory theory of the origin of spectra and opened up the possibility of actually calculating the frequencies in line spectra from the structure of the atom.

What has been said of atoms can also be said of molecules, or, indeed, of any system of particles; and continuous, as well as line, spectra can also be accounted for under the appropriate conditions. Moreover, Bohr's postulate of the existence of stationary states with definite energy levels has received direct experimental confirmation. In fact, the theory had such striking successes in the interpretation and classification of spectra, and in discussing atomic properties generally, that it gave a tremendous impetus to spectroscopy and quickly became accepted by physicists.

Nevertheless, it was recognized before long that the Bohr theory had its limitations. It seemed powerless to throw much light on some problems in atomic physics—for instance, not very much could be done about calculating *intensities* in spectra—and in some cases it seemed to give definitely wrong answers. Moreover, its basic postulates, though leading to brilliantly successful results in many instances, were not very satisfactory from the point of view of embodying fundamental laws of nature. Thus it became recognized that the Bohr theory was in the nature of a half-way house, and that some further fundamental development was necessary. Some thought that this would be in the nature of a swing back to classical ideas, but others foresaw a still more radical departure from the old laws and concepts. As events showed, the latter view was the correct one.

5. The New Quantum Mechanics

A new quantum theory was first put forward in 1925 by Werner Heisenberg. Shortly afterwards, Schrödinger developed independently an alternative form of a new theory, basing his approach on ideas previously put forward by de Broglie. Dirac and others made important contributions. It was shown soon that the alternative theories could be fuzed into one, and the new quantum theory, or "quantum mechanics" as it is often called, made great strides during the next

few years. The new theory is far more comprehensive and of wider scope than the older (Bohr—Planck) theory, but it is also more abstract and harder to describe in non-technical terms. We shall attempt to give some description of only a few of the main features.

Modern quantum mechanics lays down a definite mathematical prescription for dealing with the mechanics of atoms (or more generally of any system of particles), including their interaction with electromagnetic radiation. The mathematics involved is rather similar to that describing wave motion, and uses a "wave quantum". Quantum mechanics is therefore sometimes referred to as a "wave theory of matter". In fact, just as light must be regarded as having particle properties as well as wave properties (cf. our previous discussion of photons), so matter must be regarded as having wave properties as well as the more familiar particle properties. The fact that electrons (matter) can behave in some respects like *waves* has received direct experimental confirmation, though such a thing was inconceivable in the classical theory.

One of the most striking conclusions to which quantum mechanics has led is that, in general, it is *probabilities*, not certainties, that can be calculated. This means that we cannot be certain what will happen under given circumstances to, say, an atom. Different things may happen on different occasions, even though the initial situation is, as far as possible, identical; and the most we can do is to calculate the probabilities of the various possible happenings. Moreover, according to the celebrated *principle of indeterminacy*, enunciated by Heisenberg in 1927, the more accurately we know some quantities the less accurately we know other quantities.

The simplest example of this is found if we consider a single electron (or other particles). The principle of indeterminacy then states that the more accurately we know its position in space, the less accurately we know the velocity with which it is moving. This conclusion—completely foreign to the classical theory—is confirmed when we consider what happens when we actually attempt to determine the position or velocity of a particle, even under the most ideal conditions possible.

It may be remarked that this indeterminacy is of absolutely insensible effect when particles of ordinary size and mass are con-

sidered. It is only when we come to the excessively minute scale of distances and masses that holds within atoms that it becomes noticeable.

The fact that probability, not certainty, controls the world is, however, of considerable philosophical interest, and exhibits one of the most striking differences between the classical theory and the quantum theory. According to the classical theory, the physical world is rigidly *deterministic;* knowing the state of a mechanical system at any instant—that is, knowing the positions and velocities of its constituent particles—the subsequent behaviour of the system is completely determined, and can actually be calculated if the mathematical equations can be solved. The evolution of the whole material universe, in fact, can, *in principle*, be completely determined in the classical theory. We say, "in principle", for the mathematical equations describing the behaviour of the whole universe are, of course, far too complicated to be solved, even if we knew the exact position and velocity of every particle in the universe at the present time, which, of course, we do not.[6]

Nevertheless, that does not alter the fact that *if* we knew the exact state of the universe at any instant, and *if* we could solve the mathematical problems involved, then we could predict exactly what would happen to the universe and to every particle in it, at any subsequent time. In particular, we could predict what the ultimate fate of the universe would be. Incidentally, we could also trace the behaviour of the universe *back* in time, so that we could determine its beginning as well as its end. In brief, according to the classical theory, the present completely determines both the future and the past as far as the material universe is concerned. Whether or not such a rigidly deterministic view can be applied to life itself is, of course, another question altogether. The extreme mechanistic school would have us believe this, however, in which case we are mere automata and

[6]And, it might be added, even if we knew the exact laws governing the interaction of these particles, i.e. even if we knew the exact laws governing the behaviour of the universe. For although we obviously know a great deal about these laws, even the classical theory would hardly deny that we might not know everything. It was taken for granted in the classical theory, however, that whatever these laws were, they were *deterministic* laws, and that is the point we are here emphasizing.

all life seems, at least for many of us, to lose much of its meaning.

But according to quantum mechanics, the behaviour of the universe cannot be determined even *in principle* in such a rigid way. We cannot, in fact, even begin in the classical sense, for we cannot determine exactly—even in principle—the positions and velocities of all the particles in the universe at any instant. We can only specify, or determine, the *probabilities* that these positions and velocities have certain values at any instant. All that we can then do is to calculate what these probabilities will be at any later time. The determinism of classical physics has thus vanished into thin air. But it must be remarked that in practice we can still predict with practical certainty what the results of our experiments will be, since, as already mentioned, the indeterminacy is negligible when we deal with matter of ordinary size or mass.[7]

We shall not pursue the matter further; but perhaps enough has been said to show that we touch here on a question of fundamental philosophical importance, and one which even has a bearing on religion, namely, the question of free will versus determinism.

The new quantum mechanics enables us to calculate energy levels which are just as important as in the Bohr theory, more accurately, and further allows us to tackle a number of problems which could not be solved, or could only be partially solved, by the Bohr theory—for instance, the calculation of intensities in spectra and of line profiles. In fact, modern quantum mechanics, though by no means yet complete in every detail, enables us to deal very successfully with an amazing number of phenomena encountered in atomic physics, and theory and experiment are in excellent agreement. The new theory explains everything that the Bohr theory was able to explain and a great deal more besides. Moreover, it can be shown that the new theory is equivalent to the classical theory under the appropriate conditions, so that we may say that quantum mechanics also explains everything that the classical theory did.

Under these circumstances, it might perhaps be supposed that

[7]To put the matter another way, in our experiments, and in our daily life, we deal with enormous numbers of electrons or other elementary particles, and only statistical averages can be observed. Under these circumstances, probabilities become practical certainties.

the Bohr theory was of no further use. Such is not the case, however, for the older theory enables us to picture much more readily what is going on than does the more abstract modern quantum mechanics. In quite a number of cases, too, it will give *qualitatively,* even if not quantitatively, the right answer. It is probable, in fact, that many physicists still think mainly in terms of the Bohr theory, and regard the new theory as being of the nature of a refinement. In particular, Bohr's fundamental idea of energy levels and stationary states still holds good, as also his picture that emission or absorption of radiation consists in the emission or absorption of a photon, with the corresponding "Bohr frequency condition."

$$E_1 - E_2 = hf.$$

We can do no more than refer to an important development of quantum mechanics initiated by Dirac, designed to bring the quantum theory into harmony with the theory of relativity. This has formed the starting point for some amazing, though highly abstruse, researches of Eddington, which have, however, not yet been generally accepted.

6. Summary of the Quantum Theory

It will be seen that we have progressed a long way from the original idea of Planck that the energy of an oscillator is restricted to certain definite values, so perhaps a brief summary is in order. We may very roughly summarise the main points of the quantum theory as follows:

(1) The classical theory completely fails to explain certain observed facts of nature; for instance, the existence of atoms composed of electrons and a central nucleus, according to the classical theory the electrons would spiral in to the nucleus.

(2) According to the Bohr theory, an atom, or any system of particles can exist in a certain number of "stationary states" of definite energy in which it does *not* radiate. The energy of the atom can *only* be that of these stationary states or "energy levels", instead of being capable of assuming any value as in the classical theory.

(3) Light and electromagnetic radiation generally of a definite frequency behave, for certain phenomena, as if they were composed of particles called "photons" or "light quanta", the energy of a photon being h times the frequency, where h is Planck's constant. This particle aspect of light is *in addition* to its wave aspect.

(4) When an atom emits or absorbs radiation, the process can be visualized as the emission or absorption of a photon together with a jumping of the atom from one state to another, the resulting gain or loss of energy being accounted for by the energy of the photon emitted or absorbed. The frequencies of spectral emission or absorption lines can thus be calculated when once the energy levels have been found.

(5) The new quantum mechanics is a more thoroughgoing and radical revision of the classical theory, and provides a definite mathematical prescription for dealing with any atom, or other system, including its interaction with radiation. It gives the same picture of the mechanism of emission and absorption of radiation as the Bohr theory, but is capable of dealing with many other problems of atomic physics with which the older theory could not deal. In particular, it enables us to calculate the intensities, as well as frequencies, of spectral lines (apart from mathematical difficulties). A characteristic of the new theory is its emphasis on *probability*, rather than certainty, as the guiding principle of the material universe. It thus offers a way of escape from the rigid determinism of classical physics.

7. The bearing of the Quantum Theory on Astronomy

In considering where the quantum theory is of use in astronomy it is well, perhaps, to remind ourselves of the obvious fact that our only source of information about the heavenly bodies is the electromagnetic radiation which they emit or, in the case of the planets, which they reflect. Obviously we cannot hope to learn as much about these bodies from the radiation which comes to us from them across the vast distances of space as if we were actually to visit them (supposing, for a monent, such a thing were possible!). But it is amazing how much we *can* learn by studying this radiation.

Till comparatively recently, astronomers confined their use of this radiation to determining the direction from which it came, that is, to recording the positions of the heavenly bodies as seen from the earth. This remains, of course, an important task of astronomy. But the invention of the spectrograph opened up a much wider field of study by enabling us to obtain the *spectrum* of the radiation. The spectrum of a star usually consists of a complicated set of absorption (and in some cases emission) lines together with continuous emission and absorption regions, the lines usually appearing as superimposed on a continuous background. It is the task of astrophysics to obtain as much information as possible from these complex spectra.

One obvious possibility is to compare the frequencies of the lines in a star's spectrum with those in the spectra of known terrestrial elements or compounds, note when the frequencies agree, and thus determine what substances are present in the star. This was, in fact, almost the sole use that was made of stellar spectroscopy till some kind of *theory* of the origin of spectra was forthcoming. It is precisely here that the quantum theory is of great service. For we have seen that it enables us to calculate (except for mathematical difficulties) the frequencies and intensities of special lines, the profiles of lines, the intensity distribution in continuous spectra, etc. By comparing the theoretical results for spectra with the experimentally observed ones, much valuable information can be obtained as to the relative abundance of various elements in a star, the pressure, density and temperature of its different portions and its physical characteristics generally. Comparison of theoretical and observed *intensities* in spectra has here been especially fruitful. There are formidable difficulties of both a mathematical and an observational nature, that stand in the way; but it is amazing the amount of information which has already been gleaned about the stars, and undoubtedly more and more will be learned about them as theory and observation both progress.

We shall not attempt to go into details; but we may mention here one simple application of the quantum theory to astrophysics, which has to do with the early work of Planck (section 3). We have seen that Planck derived a formula for the intensity distribution in the continuous spectrum of the radiation emitted by a "black body", and that this intensity distribution depends only on the temperature of the body. Now it is found that the intensity distribution in the "continuous background" of most stars, including the sun, follows fairly well the Planck formula if an appropriate temperature is used. We thus derive an estimate of the temperature of the star, and incidentally conclude that most stars radiate, as far as the continuous background is concerned, approximately like a black body. This is one of the methods of determining stellar temperatures.

In its turn, astronomy has been of benefit to physics and in particular to the quantum theory; for radiation is emitted and absorbed in the stars under conditions of temperature, density and pressure

which cannot be duplicated in the laboratory, and hence a wider range of comparison between theory and observation is possible.

In conclusion, as an illustration of an astronomical application of quantum mechanics in a field other than the purely spectroscopic, we shall mention very briefly an interesting theory put forward a few years ago by H. A. Bethe to account for the energy production in stars. The stars are continually pouring out a prodigious amount of energy in the form of radiation, and in the past there has been much speculation as to the source of this energy. It is now realized, however, that the probable explanation is to be found in the energy released when the nuclei of atoms combine with each other or with other particles to form different nuclei. Such transformations of nuclei have been much studied in the laboratory in recent years.

Bethe has considered a number of possible nuclear transformations and has come to the definite conclusion that the most important source of stellar energy for most stars is a reaction cycle in which four hydrogen nuclei are combined into one helium nucleus, with carbon and nitrogen nuclei taking part as catalysts. The theory can be tested by comparison with observation on several points and very good agreement is found. It throws an interesting light on what changes are actually going on inside the stars. In the detailed consideration of the various nuclear reactions (their probability of occurrence, energy released and so on), both theory and the results of experiment are used; but in the theoretical calculations quantum mechanics plays a very essential role. In fact, Bethe's theory could not possibly have been developed without the aid of the quantum theory.

This brief sketch will, it is hoped, show that the quantum theory is of real importance in astronomy. We may confidently expect that it will continue to play an important part as more and more of the fascinating story of the heavens is unfolded.

Department of Mathematics,
University of Toronto.

THE SEQUENCE OF DAYS IN THE CALENDAR

By C. A. Chant

OF all the plans proposed for improving the calendar, that designated "The World Calendar" appears to be the favourite. Of course not every one approves of it. Not long since I received a booklet from an organization, which has the word "Liberty" in its name, strongly protesting, by words and pictures, that this calendar is a threat to our religion. In my view the adoption of "The World Calendar" will not deprive anyone of his religious freedom but may indeed make it richer and fuller.

The core of the objection raised against the proposed new calendar is that in it the regular sequence of the days of the week—Sunday, Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday, etc.—will not continue forever in that order without some interruption.

An ordinary year contains 365 days, i.e., 52 weeks and one day over, and a leap year contains 366 days or 52 weeks and two days over; and if the calendar is arranged so as to be the same year after year, which is extremely desirable, it is clear that in every ordinary year one day bearing a new name (such as "mid-year day") must be inserted among the other days and not included in any particular week, and in a leap-year two such days must be inserted. Should this be considered an interference with religious observance? I do not think so.

I have the utmost consideration for anyone who has religious difficulties, and would regret any enactment which would offend any person's religious belief.

This is hardly the place for religious argument, but perhaps I may be allowed to state my own personal views on this question.

In my childhood I was taught the Commandment, Remember the sabbath day to keep it holy (Ex. 20.8), and I have tried to observe it ever since. I have done so for two reasons: (1) I accept it as a divine command; (2) because its wisdom has been justified by social and industrial experience—one day in seven for rest and worship. In the Old Testament there are many instructions regarding the sabbath which we do not consider binding in

the circumstances under which we live and which have been superseded by the simple teaching of the Founder of the Christian religion.

We are all familiar with the incident of the Master and his disciples passing through the corn fields on the sabbath day, how the disciples plucked the ears of corn and ate them, for which they were roundly condemned by the Pharisees for doing what was not lawful on the sabbath day. Jesus defended his companions and offered some explanation of the principles of sabbath-observance. The gospel continues, "And he said unto them, The sabbath was made for man, and not man for the sabbath. Therefore the Son of Man is Lord also of the Sabbath." (Mark 2.27-28.) The matter is also referred to in Matthew 12.8 and Luke 6.5.

To me, as one accepting the teaching of Jesus, the doctrine enunciated here is that a person should not be tied to any ritual observance by any unbendable regulation, but should use his own reasonable judgment. The great principle inculcated, I take it, is to devote not less than one day in seven to rest and worship, though not necessarily the same day or days of the week. If the calendar supplies one or two more during the year, or perhaps if the Government or the Church calls upon us to observe any special day, our opportunity is all the greater.

As an astronomer I cannot understand why anyone should choose any special unalterable day as his time for worship. A day is defined as an interval of time twenty-four hours in length. Now a day, such as Sunday, November 19, at Toronto, does not coincide with any equal interval, of the same day and date, at San Francisco or Moscow or Auckland. Is one more holy than another? If you take a passage across the Pacific to Asia the name of the day used by an inhabitant there is not the same as that by your own reckoning. If you think it Sunday he will have it Monday. Which will you use? When I crossed the Pacific going west the days ran as follows:

Thursday, June 29; Friday, June 30; Sunday, July 2.

I celebrated no Dominion Day that year. On the return trip east the days were:

Friday, Nov. 3; Saturday, Nov. 4; Saturday, Nov. 4;
Sunday, Nov. 5.

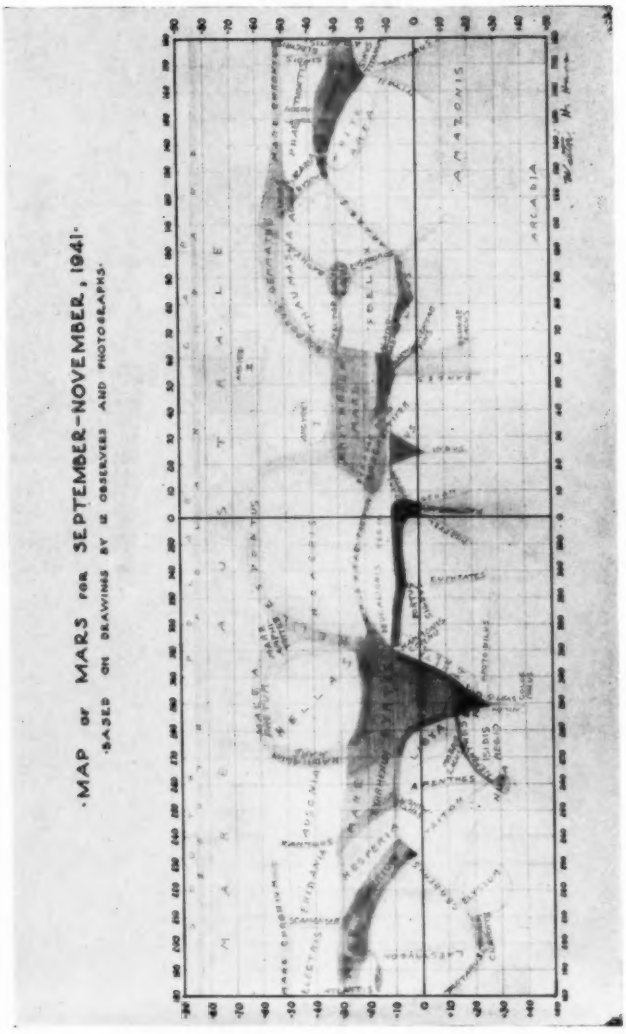
There were two days called November 4—an interpolation of a day. Special artificial devices must be employed to overcome the peculiarities in our time-reckoning encountered in travelling.

Our brethren of the Jewish faith ordinarily use for worship a different 24 hours from ours; and the Yezidis, a race in the mountains in North Mesopotamia, keep Wednesday and Friday as holy days. We should not make a fetish of any special days of the week and we should hardly do so if we remembered the most fundamental fact of all worship,—"God is a spirit and they that worship him must worship him in spirit and in truth" (John 4.24).

It may be well to remark that it is the business of the astronomer to determine the precise length of the year in terms of the day, that is, to lay down the mathematical basis for the calendar; but the arrangement of the days in the months and the months in the years should be the most effective possible for carrying on the business of life, our worship, our play, our industry.

David Dunlap Observatory,
Richmond Hill, Ont.

PLATE VIII



MAP OF MARS, 1941

PLATE IX

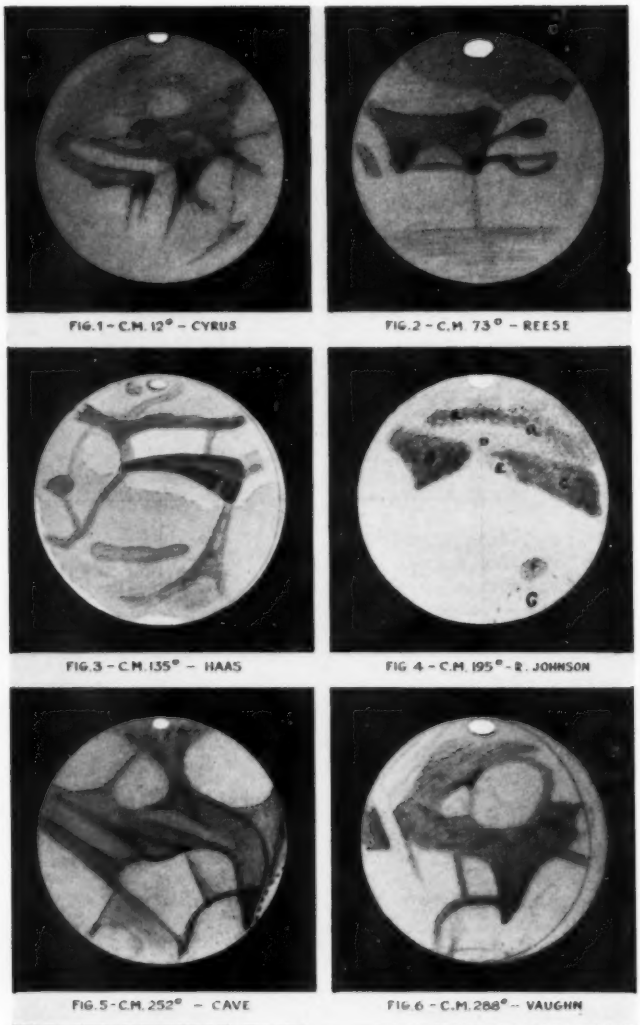


FIG. 1 - C.M. 12° - CYRUS

FIG. 2 - C.M. 73° - REESE

FIG. 3 - C.M. 135° - HAAS

FIG. 4 - C.M. 195° - R. JOHNSON

FIG. 5 - C.M. 252° - CAVE

FIG. 6 - C.M. 288° - VAUGHN

THE 1941-2 APPARITION OF MARS

(With Plates VIII and IX)

By WALTER H. HAAS

INTRODUCTION

FOR observers in middle northern latitudes the 1941-2 apparition of Mars was probably the most favorable of the 15-year cycle. Conditions for observing were better than in 1939 because of the much greater altitude in the sky. This paper will report observations carried out by a group of mostly American amateurs. Opposition occurred on October 10, 1941, when the declination of Mars was $+3°$; the nearest approach came on October 3, when the apparent angular diameter was 22″.8. These dates and all other dates in this paper are by Universal Time.

I list below those observers on whose work this paper is based. Some of them have submitted only part of their records, but the

TABLE I.

THE OBSERVERS

Name	Telescope	Station	Remarks
D. P. Barcroft	6″ reflector	Madera, Calif.	
R. Barker	12″ "	Cheshunt, Herts. England	
T. R. Cave, Jr.	10″ "	Long Beach, Calif.	
C. M. Cyrus	10″ "	Lynchburg, Va.	
W. H. Haas	6″ "	New Waterford, Ohio	
W. H. Haas	18″ refractor	Upper Darby, Pa.	Flower Observatory
H. M. Johnson	8″ reflector	Des Moines, Iowa	
H. M. Johnson	5″ "	Rochester, N.Y.	R. T. Smith's telescope
R. G. Johnson	5″ "	Le Grand, Iowa	
R. G. Johnson	10″ "	Le Grand, Iowa	
R. G. Johnson	8″ refractor	Des Moines, Iowa	Drake Observatory
E. Reese	6″ reflector	Uniontown, Pa.	
E. A. Sill	8″ refractor	Mamaroneck, N.Y.	
J. R. Smith	8″ reflector	Lubbock, Texas	
F. R. Vaughn, Jr.	8″ "	Des Moines, Iowa	
F. R. Vaughn, Jr.	8″ "	Des Moines, Iowa	H. M. Johnson's telescope
F. R. Vaughn, Jr.	7″ "	Des Moines, Iowa	
F. R. Vaughn, Jr.	5″ "	Rochester, N.Y.	R. T. Smith's telescope
E. K. White	5″ "	Ymir, B.C., Canada	
L. J. Wilson	12″ "	Nashville, Tenn.	Used for photography

amount of material on hand is quite sufficient to give a good picture of Martian events in 1941-2.

Observations by our group extend from December 21, 1940, to June 26, 1942; but the most and best work was done in September, October, and November, 1941. In the rest of this paper the year will not be stated when 1941 is meant.

The next table gives the values of three physical quantities during the observations: D, the apparent angular diameter of the planet; ⊙, the areocentric longitude of the sun measured so as to be 0° at the vernal equinox of the northern hemisphere of Mars; and D ⊕, the areocentric latitude of the earth, called negative when south. It should be noted that near opposition the southern hemisphere of Mars was close to its summer solstice and that the south pole was then tilted toward the earth by about 20 degrees.

TABLE II.

PHYSICAL DATA ON MARS IN 1941-2

Date	D	⊙	D⊕
1941, January 1	4″3	124°	+11°
March 1	5.5	154	− 4*
May 1	7.8	188	−19
July 1	11.8	225	−22
August 1	15.1	245	−20
September 1	19.6	264	−18
October 1	22.8	283	−19
November 1	19.7	302	−23
December 1	14.2	319	−24
1942, January 1	10.2	336	−23
March 1	6.3	6	−13
May 1	4.6	34	+ 2
July 1	3.8	61	+16

*Value obtained by linear interpolation.

THE COMPOSITE APPARITIONAL MAP

A map of Mars, based upon 297 drawings and numerous notes by the 12 visual observers and some dozens of photographs by Wilson, is presented in Plate I. No feature is shown unless it appeared on the drawings of at least two observers or else on the photographs. Though no hard-and-fast rules could be followed, I

sought to weigh all evidence carefully and to proceed objectively in preparing the map. Positions on the map were guided by the quantitative determinations described below, though they do not conform exactly. The map shows the planet as it was in September-November. The south cap and the south polar band are represented as they were at opposition, at which time the north cap and its polar band were seldom seen. The map is on a cylindrical equal-interval projection.

Positional Determinations

Three programs of positional work based upon 1941 data were carried out:

1. I measured the latitude β and longitude λ of 40 selected points on those 75 of my drawings made when the apparent angular diameter exceeded 10″. These drawings extended from June 19 to December 27. Each mark was measured on an average of 17 drawings. The measures were reduced by trigonometric methods giving most accurate results near the centre of the disc. The internal errors of this method were investigated for eight marks apparently typical of the entire 40; the average probable error of a single measured position came out to be 5°.4 in latitude and 6°.9 in longitude. The error in longitude appears to increase with increasing numerical latitude.

2. I determined longitude by a program of visual central meridian transits of suitable features, a method familiar to students of Jupiter.[1] This program extended from June 21 to December 27, but most of the observations were made in July and August. The phase being large during those months, I usually timed not when marks were on the central meridian but instead when they were midway between the limb and the terminator. There were obtained 223 transits on 34 marks. Longitudes were derived by trigonometry. In the computation it was necessary to assume a latitude β for the mark, but it is most improbable that uncertainties in β have caused errors exceeding a degree in the averaged longitude of any mark. The internal errors were investigated for seven apparently typical marks. For them the average value of the probable error of a single transit was 1°.7, a value near the probable error of a Jovian transit.[2, 3]

3. Wilson's photographs were measured for the latitude of 25 marks by Vaughn. These photographs extend from August 27 to October 23. Vaughn used only features near the central meridian and applied a mathematical method there suitable. In his report he assigns weights of one to five as a measure of accuracy, five for the best determinations, and estimates the corresponding probable errors of his averaged photographic latitudes as 2°.0 to 0°.2.

For 30 marks it was possible to compare the longitude from drawings λ_D and the longitude from transits λ_T. The average value of the residual $\lambda_D - \lambda_T$ and its probable error are $2°.9 \pm 0°.6$. It appears certain that drawings gave significantly larger longitudes than transits, and probably most of the systematic error lies in the drawings.

For 15 marks it was possible to compare the latitude from drawings β_D and that from photographs β_P. The average value of the residual $\beta_D - \beta_P$ and its probable error are $-3°.5 \pm 1°.0$. This difference can hardly be ascribed to chance, and it appears clear that I drew marks too far south.

Table III summarizes positional work. The first column employs these abbreviations: S for south, N for north, P for preceding end in longitude, C for centre, and F for following end in longitude. The sixth column gives the adopted 1941 longitude, in computing which one transit was given the same weight as four drawings. The seventh column gives the adopted 1941 latitude, the photographs being here given much the greater weight. The eighth and ninth columns supply the position determined in 1939 when it is available.[4] The tenth column gives the number of transits T and drawings D used in the 1941 determination and the photographic weight P reported by Vaughn.

There is some evidence in Table III that the northern shoreline of the *maria* from $\lambda\, 0°$ to $\lambda\, 170°$ was about four degrees farther north in 1941 than in 1939. On the whole, however, latitudes for the two apparitions do not differ significantly; nor do longitudes do so after those few considerably larger 1941 longitudes noted above are excluded. This result is opposed to Pickering's large positional shifts for some Martian features,[5] but final judgment must be suspended.

TABLE III.

1941 POSTIONAL DETERMINATIONS

Mark	λ_D	λ_T	β_D	β_P	$\bar{\lambda}$	$\bar{\beta}$	λ 1939	β1939	Data
N tip p fork Aryn...	2°	0°	+ 1°	+ 4°.3	1°	+ 3°	355°	− 2°	20D, 12T, P4
N tip f fork Aryn....	9	3	+ 1	+ 4.3	5	+ 3	0	− 2	20D, 12T, P4
N tip Margaritifer...	23	25	− 3	+ 4.8	24	+ 2	18	− 3	23D, 11T, P3
S tip Acidalium.....	29	26	+27	....	27	+27	24	+35	11D, 6T
N tip Aurorae.....	53	53	− 8	− 4.8	53	− 6	56	− 5	20D, 9T, P3
C Lunae.....	65	66	+17	+24.6	66	+24	...	....	8D, 7T, P3
N tip Tithonius.....	80	83	− 1	+ 2.1	82	+ 1	81	− 6	19D, 8T, P1
C Solis.....	86	93	−29	−28.0	89	−28	85	−28	13D, 2T, P4
F Solis.....	...	89	....	....	89	....	...	....	1T
S border Thaumasia	...	...	....	−43.0	...	−43	...	−46	P3
F Tithonius.....	104	93	− 8	....	97	− 8	101	− 8	17D, 8T
C Phoenicis.....	...	106	....	....	106	....	...	....	2T
N tip Aonius.....	118	110	−32	....	112	−32	112	−34	10D, 7T
N p Chronium[1]	116	...	−55	....	116	−55	...	....	12D
P Sirenum.....	127	130	−44	−29.6	128	−33	128	−35	17D, 4T, P3
N base Thermodon[1]..	154	150	−49	....	152	−49	...	....	11D, 4T
S base Thermodon[1].	157	...	−59	....	157	−59	...	....	12D
N tip Titanum.....	171	163	−26	−15.0	167	−18	164	−22	26D, 7T, P4
C S base Amazonis shading.....	168	...	+ 1	....	168	+ 1	159	0	9D
C N edge Atlantis...	183	178	−31	....	181	−31	...	....	18D, 3T
S p Cimmerium[2]....	181	...	−38	....	181	−38	162	−39	20D
N edge bright bay following Titanum	...	...	....	−27.0	...	−27	...	....	P1
S base Laestrygonum	204	...	−26	....	199	−26	...	....	11D
N tip Laestrygonum.	...	196	....	−17.8	199	−18	202	−18	5T, P4
N tip Charontis.....	201	200	+24	....	200	+24	205	+25	18D, 5T
C Charontis.....	...	...	....	+18.0	...	+18	...	....	P3
C rift in Cimmerium[3]	201	202	−32	....	202	−32	187	−31	9D, 3T
N edge Cimmerium following Laestrygonum.....	...	...	....	−25.1	...	−25	...	....	P2
F Charontis.....	...	212	....	....	212	....	216	+12	1T
C rift in Cimmerium[3]	226	...	−25	....	226	−25	209	−27	6D
S p Tyrrhenum[1]....	233	...	−41	....	233	−41	235	−37	19D
N tip f Cimmerium..	237	232	− 7	+ 2.3	234	− 1	231	− 3	27D, 10T, P4
C N edge Hesperia..	244	243	−10	....	244	−10	...	....	20D, 4T
F dark band N edge Hesperia[1].....	248	...	−12	....	248	−12	257	− 3	8D
S border Tyrrhenum	...	...	....	−28.7	...	−29	...	....	P2-3
N tip Syrtis Minor..	251	254	− 8	....	253	− 8	257	− 4	25D, 8T
C Hesperia[4].....	...	254	....	....	254	....	...	....	3T
S tip Nuba[5].....	262	257	+25	+21.5	261	+23	255°	+34	10D, 1T, P1-2
Junction Tyrrhenum and Syrtis shores	276	266	− 7	− 2.0	270	− 4	277	− 6	27D, 10T, P4
C N base Hadriacum	273	...	−24	....	273	−24	...	....	16D
C S base Hadriacum	275	...	−48	....	275	−48	...	....	15D
C Moeris.....	275	275	+16	....	275	+16	...	....	8D, 1T
Junction Nepenthes and Syrtis Major	...	...	....	+ 8.2	...	+ 8	...	....	P3
C Coloe.....	295	287	+40	+38.5	289	+39	...	....	8D, 6T, P3

TABLE III.—*Continued*

Mark	λ_D	λ_T	β^D	β^P	$\bar{\lambda}$	$\bar{\beta}$	λ_{1939}	β_{1939}	Data
N tip Syrtis Major ..	294	287	+26	+26.2	289	+26	288	+26	23D, 12T, P4
N border Hellas[6]	...	...	....	−26.9	...	−27	...	−37	P5
S border Hellas.....	...	...	....	−58.9	...	−59	...	....	P2-3
Junction Syrtis and Sabaeus shores...	311	307	− 8	− 9.4	309	− 9	308	− 8	27D, 9T, P4
P N base Hellespontus[3].....	310	313	−18	....	312	−22	...	....	28D, 10T
F N base Hellespontus[3].....	323	319	−19	....	320	−22	...	....	28D, 13T
C N base Hellespontus[3].....	...	...	....	−25.0	...	−22	305	−18	P2-3
C S base Hellespontus[7].....	333	...	−53	....	333	−53	321	−44	21D
N shore Sabaeus.....	...	...	....	− 9.3	...	− 9	....	....	P4
N tip Sigeus.....	336	333	− 5	....	334	− 5	337	− 7	20D, 11T
C Ismenius.....	346	340	+29	....	342	+29	337	+34	12D, 8T

[1]The 1941 latitude is very probably *about* 10 degrees too far south.
[2]There was certainly a change in longitude between 1939 and 1941.
[3]There may well have been a change in longitude between 1939 and 1941, but some question of correct identification exists.
[4]This position is very indefinite.
[5]It appears very probable that this mark was farther south in 1941 than in 1939.
[6]The 1939 latitude was taken from just one photograph.
[7]A change in position between 1939 and 1941 appears likely.

DESCRIPTION OF THE SURFACE

This section of the paper is based upon a *careful* and *thorough* study of 297 drawings and some dozens of Wilson's photographs. The large number of drawings and the comparatively large number of participating observers often permitted the settling of apparent contradictions which would otherwise have been unresolved. The marks are described in roughly the order of increasing longitude. Unless changes are mentioned, the features were apparently stable in aspect.

The forks of Aryn were darker than the rest of Sabaeus. They were less easy to separate than in 1939-40; e.g., I could divide them only when the angular diameter of Mars exceeded 13″. In late July the forks shared in the pronounced darkening of Sabaeus.

Aryn and Margaritifer were usually seen separated by a region having the same color and brightness as the northern deserts. However, Cyrus and I sometimes observed Jani Fretum as a

faint narrow band. My drawings in late August and mid-November show Jani varying in intensity over periods of only a few days.

Margaritifer was triangular in shape and tapered to a pointed north tip. It was only moderately dark near opposition but surpassed Mare Erythreum to its south. Cave and H. Johnson show it separated from this *mare* by a thin rift. My long series of drawings indicates that Margaritifer darkened between July, 1941, and January, 1942.

The region south of Aryn and Margaritifer was only slightly duller than the northern deserts in its middle latitudes but was more dusky near the pole, where Mare Australe existed. The north shoreline of this *mare* was a continuation of that of Hellespontus. Fully seven observers sometimes drew a faint dark column joining Erythreum and Australe. Cyrus saw this column better on September 28 than on October 2. On August 20 Vaughn observed a large circular very dark feature just south of Aryn. This object was very transient, being seen neither by Vaughn nor the others before August 20 nor after August 22. On March 30, 1942, I observed Australe to be intense in these longitudes, a distinction no longer present in early May.

Four observers recorded Gehon as a canal emanating from the following fork of Aryn. Cave, however, drew Gehon only as the edge of a dusky shading; and Cyrus and Vaughn occasionally compatibly observed the space between Gehon and Hiddekel to be shaded. Indus was one of the easiest canals on the planet, being drawn by nine observers. They agree that Indus was notably narrow. H. Johnson and I occasionally observed Deuteronilus canal in July and August.

Acidalium (or perhaps Acidalium-Niliacus) was a very inconspicuous object near the north cusp during most of the apparition. Observations by Cave, Vaughn, H. Johnson and me from February 23 to April 8 show it then very faint. In May and June Acidalium was invisible to H. Johnson and Vaughn. Mars being now closer, H. Johnson and I drew this feature in July and August as a *light* hump-shaped object. It subsequently effectually disappeared and was not observed during September, October, and November, except that Cyrus once saw it faintly in excellent seeing. In December I again saw Acidalium vaguely. It continued to darken

early in 1942 and by late March was extremely dark, an aspect preserved into early May (perhaps even into June), when it was a large wedge-shaped object.

In the deserts north of Aryn and Margaritifer, as in other portions of the planet, I occasionally drew transient bright areas near or at the limb or terminator, areas not seen when more centrally placed on the disc. Such areas are more rare on drawings by the other observers, nor were they intense enough to show on Wilson's photographs. A whitish area drawn on the terminator near λ 15° on July 14 is of interest as being perhaps identical with one drawn on July 16 *about* 15 degrees of Martian latitude farther south.

Some of the better views revealed Pyrrhae Regio as a lighter shading between Margaritifer and Erythreum. The broad and moderately dark latter *mare* existed between the longitudes of Margaritifer and Aurorae. Cave and I drew Erythreum darkest on its north shore. I thought this *mare* darker in December than earlier in the apparition.

Sinus Aurorae was about the same darkness as Margaritifer and surpassed adjacent *maria*. Cave and H. Johnson found Aurorae detached from other *maria* by a rift, and Cyrus compatibly drew a faint shading to its south. Whether the north shore of Aurorae was rounded or pointed is uncertain. I thought this *mare* darker in December and the next month than it had previously been.

The region south of Erythreum was only slightly duller than the northern deserts in middle latitudes but was more dusky in high latitudes because of the presence of Australe. Five observers recorded Argyre I as a perhaps circular well-defined white area. Vaughn, Smith, and I each once saw Argyre II as a white area on the limb or terminator.

Nilokeras canal, joining Acidalium and Lunae, was visible to H. Johnson only as a fairly easy object on July 23. Jamuna, joining Acidalium and Aurorae, was seen by me alone. Faint in good seeing on July 16, Jamuna was as strong as Ganges on August 20. On August 21 it was fainter, and on August 23 and later it was invisible. Four observers drew Ganges as a canal definitely wider than Indus, but Cave instead recorded a broad dusky shading. Drawings by Cyrus in good seeing resolve the seeming contradiction by showing a canal on the preceding edge of Cave's shading.

Lunae Lacus was usually a faint feature, but H. Johnson on July 23 in splendid seeing drew it very dark and greatly elongated. Cyrus saw Lunae more easily on October 30 than on October 2 under better conditions. Cave, Sill and Cyrus recorded Juventae Fons, which was *tiny* and black. Cyrus and Sill saw Baetis, a thin and very dark canal joining Juventae and Aurorae.

Features along the north edge of Thaumasia were rather difficult to observe, probably chiefly because of their smallness or narrowness. A consensus of drawings, however, shows Tithonius Lacus as two bands joining at a very obtuse angle near λ 80°. Cave, Sill, Barker, and I saw a strong Agathodaemon canal between Aurorae and the preceding end of Tithonius. Sill, H. Johnson and Reese drew Tithonius darker in its preceding half than in its following half. This *mare* probably averaged lighter than Aurorae. R. Johnson drew a large diffuse whitish area just north of Tithonius on September 23, and Sill and I observed similar features near November first.

An inconspicuous Solis Lacus was oval-shaped, the east-west axis being about twice as long as the north-south axis. First seen in July, Solis was then very faint to me. From August 14 to 18 it was probably lighter than in July. From August 20 to 24 I could not see it with any certainty, even when aided by splendid seeing. This extreme vagueness was apparently fairly brief, for Smith observed Solis readily on August 27. In late September it was comparatively dark, being then drawn by eight observers and showing faintly on Wilson's photographs. In late October Solis was much as a month before. I thought it to be growing somewhat fainter in early November, recorded it to be light again near December first, and failed to see it in January, 1942, and later.

Nectar was one of the easiest canals on Mars. It was seen by eight observers and shows faintly on photographs. The position and curve shown on the map are those indicated by photographs. The drawings of Cave and me suggest that this canal was slightly wider at its preceding end than at its following end. The darkness of Nectar regularly equalled that of Solis and hence showed the changes in intensity described above. Other canals in Thaumasia were delicate, though perhaps numerous. The map shows those that were sufficiently confirmed.

Wilson's photographs show Thaumasia a trifle duller in tone than the northern deserts. They reveal part of Thaumasia whitened on the sunrise limb on September 30. Cyrus, Vaughn, and I each once saw a similar whitening in this region when at the edge of the disc. On some occasions I found Thaumasia dusky, as Barcroft once did. In particular, its south part was observed strongly shaded on February 14, 1942, an aspect perhaps gone by February 19.

Bosporus Gemmatus formed a curving boundary to Thaumasia on two sides. The photographs apparently demonstrate that Gemmatus was lighter than Erythreum and wider than Tithonius. Gemmatus was probably broadest and darkest near its following end, where Sinus Aonius exsited. The photographs show a rift or lighter shading between Gemmatus and Erythreum, which rift Reese and I saw. A drawing by Cave shows Bathys canal having a dark extension into Gemmatus, and I confirmed this mark to the extent of drawing a dark projection on the south shore of Gemmatus near λ 105°. My drawings appear to indicate that this *mare* was lighter from December onward than from July to November except that it was extremely dark in part in February, 1942.

Wilson's photographs show Australe lighter south of Gemmatus than between λ 0° and λ 60°.

Four observers saw Hyscus as a faint and probably thin canal continuing the curve of the north shore of Gemmatus from the tip of Aonius to the preceding end of Sirenum. Araxes was a broad and conspicuous canal observed by eight members of the group. I found Araxes "unexpectedly light" on November 4.

A number of observers saw or suspected a slight duskiness of the deserts north of Tithonius. Cyrus and I sometimes drew a canal extending in a north and following direction from the following end of Tithonius. In the northern deserts between λ 60° and λ 130° Cyrus, Vaughn, Barcroft and I occasionally drew white areas near or at the limb or terminator. Two of these areas endured for at least four days. Fortuna and Iris canals, usually appearing as broad bands but looking narrow in excellent seeing, and Ascraeus Lacus were seen by me in July and August but were subsequently invisible. On February 11, 1942, and on May 30,

1942, I observed a notably dark northern area perhaps lying over Arcadia.

Mare Sirenum was darker than most other *maria*. The outline on the map follows the photographs except for the following end, where it was necessary to reach a decision from contradictory drawings by visual observers. The drawings do appear to show, however, that the following end lay at a longitude larger than in 1939 by about 10 degrees. Barker and I agreed that there was an *immense* amount of *delicate* internal detail in Sirenum, but only Cyrus and I were able to draw much structure to the *mare*. The darkest portion was the pointed Sinus Titanum. H. Johnson and Cyrus observed the preceding end of Sirenum to be detached from the rest of the *mare* by a rift or light shading. Cyrus, Cave and I sometimes drew an oval bright area along the north shore of this *mare*.

Mare Chronium was a narrow and rather inconspicuous band lying south of Sirenum. Chronium was widest and darkest near its preceding end. Cyrus and I saw this *mare* better in October than in August or September; the increase in darkness thus indicated harmonizes with the work of some of the others. Chronium probably retained its October intensity at least until January, 1942. Some drawings by Sill and me suggest that its intensity was at times subject to rapid and large variations.

Sirenum and Chronium were connected by the light and fairly narrow canals Thermodon and Simois. Icaria and Phaethontis, the regions separating Sirenum and Chronium, were slightly brighter than Mare Australe between λ 130° and λ 180°. In the autumn Australe was here very light, indeed only slightly duller than the northern deserts. H. Johnson and Vaughn saw Australe to be notably dark here in April, and my drawings in July and August suggest an intermediate intensity then.

A light but very large shading was observed over Amazonis. This shading tapered to a point at Sinus Titanum, as shown on the map. I observed the shading to be darker in February-May, 1942, than it had been in 1941. The southern portion of the shading had as edges two canals emanating from Titanum, Titan (or perhaps Gigas) on its preceding side and Tartarus on its following side. These canals were darker than the dusky space between

them. Vaughn's results suggest that Titan was one of the strongest canals on the planet in April and July. Probably usually less conspicuous than Titan, Tartarus exhibited variations. I saw it easily in early July and on August 9 but found it faint on August 13 and invisible on August 16 and 18. It was recorded by Cave on September 12 and 15 and by Vaughn on September 14, but it was not seen by Cave on September 17 and 20 nor by me on September 23 and 24. A fading is hence well-evidenced. Tartarus had apparently recovered its earlier conspicuousness by October 6, when Barker drew it.

Atlantis was a dusky and fairly broad strait between Sirenum and Cimmerium. Its darkness and general inconspicuousness are emphasized by the fact that on Wilson's photographs it blends invisibly into the two *maria* beside it.

Though fairly dark, Mare Cimmerium averaged lighter than Mare Sirenum. The outline given Cimmerium on the map follows photographs where possible. The preceding side of this *mare* lay along a meridian and no longer possessed its 1939 aspect.[4] The internal shading of Cimmerium was very complex. The north following tip was the darkest portion of this *mare*. In 1939 this tip had developed as a pointed dark projection from the north shore near λ 234°.[4] This projection was seen plainly in 1941-2 for many months on both sides of opposition. An unexpected feature of 1941 observations was an oval bright bay that indented the north shore of Cimmerium near λ 190°. This bay was seen only in September and October, but the evidence for its absence at other times is inconclusive. Another unexpected feature was a large dark projection located on the north shoreline near λ 199° and looped around the north edge of the bay. This projection was seen well only in September and October, but there is good reason to think that it had a far longer duration. It was assumed to be a strongly developed Sinus Laestrygonum.

Mare Chronium existed as a narrow band south of Cimmerium. Cyrus found it darker following λ 175° than preceding that longitude, and Sill and I confirmed this aspect. Three observers show Chronium bending southward near λ 210°. The photographs appear to show a darkened following end near λ 230°.

Four observers reported a light and fairly narrow Scamander canal joining Cimmerium and Chronium. The same number saw Xanthus, and photographs confirm that it existed as a broad band separating Eridania and Ausonia. Electris and Eridania, the regions between Cimmerium and Chronium, were slightly brighter than Mare Australe between λ 180° and λ 240° and were often seen brighter than usual when on the limb or terminator. Australe between λ 180° and λ 240° behaved the same way as between λ 130° and λ 180°. R. Johnson recorded a very dark spot *near* λ 225°, β − 65° on July 4 and 7; neither he nor others recovered this spot in August and later.

Trivium Charontis was rather ill-defined at times. A study of the data appears to show clearly that this feature was wedge-shaped, tapering somewhat from its north preceding side to its south following side. Although there is no evidence of *progressive* variation in the darkness of Charontis between June and November, *irregular* and probably fairly rapid changes in intensity were observed by R. Johnson and me and perhaps also by three of the others.

Laestrygon canal was recorded by five observers; I found it more easily visible in July and August than in September-November. Trivium Charontis tapered into a southern extension, Cerberus canal, seen by seven observers and photographed by Wilson. The south end of Cerberus connected to Cimmerium a little preceding the 1939 projection. Triton canal, at least approximately a continuation of the curve of the north shore of Cimmerium, was drawn by six of the group. Elysium was recorded as a round whitish region by five observers, most regularly by Cave. The other four saw it intermittently, and there is good reason for suspecting irregular variations. Cave, Cyrus, and Barker observed the northern deserts to be very slightly dulled between Laestrygon and Cerberus. H. Johnson and Cyrus drew an unidentified canal running from Charontis toward Nuba.

Hesperia was a broad strait between Cimmerium and Tyrrhenum. Its duskiness made it inconspicuous. Dark bands on the north and south edges of Hesperia were reported by several observers.

Mare Tyrrhenum was seen in widely varying aspects by different observers; the map gives the outlines shown on photographs. Little or nothing protruded from the north shoreline to mark Syrtis Minor. In its average darkness Tyrrhenum equalled Cimmerium. Much *delicate* detail was suspected inside Tyrrhenum.

South of Tyrrhenum lay Ausonia, a large and whitish region. Vaughn and I found it brighter near the limb or terminator than when more centrally located. Vaughn recorded it to be much brighter on the sunrise limb on September 14 than on July 5 with about the same meridian central. On November 17 Vaughn and I saw Ausonia surprisingly bright and nearly merged with the bright region Hellas. Observations by Barcroft on November 14 and by Smith on November 15 are confirmatory, and a change appears certain. The altered aspect continued visible to me on November 20, in December, and in January, 1942.

Mare Hadriacum was in early October a wide and fairly dark band. Photographs show it much fainter in early September than in October. R. Johnson and I found it about the same in early August as in September. After opposition Hadriacum faded and was thin and faint to four observers in mid-November (when Hellas and Ausonia almost merged); in fact, Barker drew it already very thin on November 2.

Australe south of Ausonia was vague near opposition, though again there is evidence that it was darker in June and July. Photographs show a darker portion near λ 250°, an area seen by one visual observer.

Cyrus, Vaughn, Barcroft, and I occasionally drew Amenthes, a delicate canal connecting Syrtis Minor and Nuba. These observers and Cave also saw a faint unidentified canal joining Moeris Lacus and Tyrrhenum. Libya was drawn slightly dusky by Cave on October 17 and by Vaughn on November 17, and near December 20 Cave observed it to grow darker.

Nuba was an inconspicuous and small hump-shaped marking near the north cusp during the favorable portion of the apparition. First seen near August first, it grew slowly and steadily darker and had become intense by March-April, 1942.

In October Nepenthes canal was a striking object, unquestionably more conspicuous than any other canal in 1941-2 or than any

canal observed during the 1937 and 1939-40 apparitions. Nepenthes showed a characteristic loop-shape in joining Nuba to Syrtis Major and passed through Moeris Lacus, an oasis which Cave and I found darker than the canal. Nepenthes was observed in late June, near August first, and near September first; but there is good evidence that it was at those periods lighter than in October. The October intensity continued into November and, according to Cave, into December also. In January-March, 1942, I *suspected* that Nepenthes was less conspicuous than in the preceding autumn. This canal possessed an appreciable width.

Nilosyrtis was a usually inconspicuous canal that extended from the north tip of Syrtis Major northward to a usually faint oasis, Coloe Palus. Faint in June, the canal and the oasis were much stronger near August first. Near September first I found them notably dark. Vaughn confirms this character of Nilosyrtis, and Wilson's photographs appear to show it better near September first than in October. The observers agree that in October and the three succeeding months Nilosyrtis and Coloe were difficult features.

On June 26 and 30 Isidis Regio looked very white to H. Johnson.

Syrtis Major was roughly triangular; but the preceding and following shorelines were not symmetric with each other, and some drawings suggest strongly that these shores were complex curves. The north tip was pointed. Syrtis was darkest near its north end, W. H. Pickering's Euxinus,[6] which was one of the darkest places on the planet. The following shore was also extremely dark. The preceding shore was less dark. Still less conspicuous was a dark southern border. Up to the end of May H. Johnson suspected that Syrtis was unusually light. On June 19, 21 and 22 it was difficult to see near the terminator. H. Johnson on June 23 and Vaughn two days later found Syrtis faint and notably shortened, the north end lying near $\beta + 5°$ (compare with Table III). On June 26 H. Johnson confirmed this blunting, though it was now less pronounced. During the rest of 1941 Syrtis was of normal length and was probably darker than any other *mare* but Sabaeus. The preceding part of Euxinus looked comparatively light to me on September 6 and to Cave on December 23. On February 2, 1942, I found Syrtis surprisingly faint; and about a month later I suspected its north half of having lightened. On June 26, 1942,

I saw Syrtis less well than other *maria*. Photographs and three visual observers show the deserts diffusely brightened along the following shore of this *mare*, probably most so when near the sunrise limb.

A roughly circular Hellas was the most conspicuous of the southern bright areas. Early October photographs show its edges dusky so that the area of the bright portion was reduced; and Sill, Smith, and R. Johnson found Hellas small in early October. These dusky edges are not present on photographs near September first. Hellas was brighter near the limbs than near the central meridian. Cyrus, Cave, and I occasionally perceived that the north part of this area was brighter than the south part. Vaughn found Hellas inconspicuous in May and June. I found it unusually bright on August 3 and 5. Vaughn observed it to be much brighter on September 1, when Sill confirmed its conspicuousness, than on the next date. I recorded it as brighter on September 7 than on September 6, Vaughn finding it "quite bright" on the later date. Wilson's photographs show Hellas dimmer in early October than a month before, and Vaughn commented on its dullness on October 6. On November 13, 14, and 17 I found the region notably bright, as did Barcroft on November 14, and still saw this increased brightness in December and in January, 1942.

Hellespontus was a curving dark band outlining the preceding and south edges of Noachis and darker on the preceding edge of Noachis. Many observers failed to distinguish the south arm of Hellespontus from Mare Australe to its south. The aspect of Hellespontus along the following side of Hellas was similar to that of Hadriacum along the preceding side of this region. Hellespontus was probably darker than in 1939; and it may have grown darker between July and January, 1942. I observed it to be faint and diffusely outlined on July 22 and 23 but normal again on July 24 and later.

Malea and Amphitrites formed an inconspicuous dark southern border to Hellas. Australe was dusky south of Hellas, darker than preceding λ 270°.

Sinus Sabaeus was by far the darkest and thinnest of the *maria* during much of the apparition. Its north shore curved slightly northward from λ 309° to λ 334° and then slightly southward from λ 334° to about λ 359° (note Table III). Portus Sigeus was some-

times seen as a small pointed hump; but the best views of Cyrus, Cave, and Smith show it as two tiny humps. Sabaeus was detached from Syrtis Major by a rift, or perhaps a light shading; Cave and I sometimes recorded a more delicate rift or shading just preceding Aryn. In May and June Sabaeus was comparatively light, no darker than Margaritifer or Aurorae. I observed Sabaeus to darken considerably between July 18 and 26. Vaughn found it rather light again on August 20, as I did three days later; but from August 27 to the end of the year it was intensely dark.

Pandorae Fretum was a band joining the north part of Hellespontus and the south part of Margaritifer. Pandorae was somewhat narrower than Sabaeus and was rather light, being darkest near its preceding end. In July it was a delicate object, and near September 1 it was still faint. In October it was plainly present and was darker than before. It was also easy to see in November and December and may have remained visible during the first three months of 1942.

Deucalionis Regio was whitened and brighter than a slightly dulled Noachis. Australe was dusky in the longitudes of Sabaeus. On October 2 Smith, and perhaps Cyrus also, saw a large white area over Noachis and Australe. Smith drew a gap in Pandorae at the north edge of the area, much the aspect that Martian clouds would cause.

Protonilus was a delicate canal occasionally recorded by Cave and me. Euphrates canal was seen comparatively well in June, less readily in late July and near the end of August, and only occasionally in October and November. It was darker by late December, according to Cave. I observed Ismenius as a small and light oasis in July and August, and this mark was perhaps drawn by H. Johnson on June 23. Subsequent to August none of the observers recorded Ismenius. Four observers saw Hiddekel as a canal emanating from the preceding fork of Aryn. Never notable, this canal perhaps imitated the intensity-variations of Euphrates.

The group of observers succeeded in recording several dozen canals. They quite failed, however, to ascertain the true aspect of these delicate features. It is worthwhile to point out that what was perceived by one observer as a narrow dark band was frequently perceived by another observer as the boundary between two regions of slightly different intensities.

(To be concluded)

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Solar Observations by Amateurs

The American Association of Variable Star Observers, with which a number of our members are affiliated, has recently organised a group of old and new members for the purpose of observing the sun and sunspots. The A.A.V.S.O. has appointed as chairman of its committee Mr. Neal J. Heines, 560 Broadway, Paterson 4, New Jersey, U.S.A. Observers contemplating co-operation in this important branch of astronomy should write to Mr. Heines for full particulars, instructions, and report blanks.

F. S. H.

Award of The Franklin Medal to Dr. Shapley

The Franklin Institute has announced the selection of Dr. Harlow Shapley, Director of the Harvard College Observatories, as 1945 winner of the Franklin Medal. The award is "in consideration of his many valuable contributions to the science of astronomy, and especially of his work in the measurement of the vast distances necessary for the determination of the nature and extent of our galaxy, as well as of those other galaxies external to ours."

The Franklin Medal award is made to "those workers in physical science or technology, without regard to country, whose efforts have done most to advance a knowledge of physical science or its applications." Edison, Marconi, Jeans, Orville Wright, Einstein, Kapitza and W. D. Coolidge are among the familiar names of past recipients of this medal.

When Franklin's own versatility and participation in so many fields of scientific and cultural endeavour are recalled, it is interesting to note that Dr. Shapley is president of the American Astronomical Society, of the National Society of Sigma XI, and Science Clubs of America, Chairman of the Board of Science Service, the Worcester Foundation for Experimental Biology, and the World Wide Broadcasting Foundation. He is past-president of the American Academy of Arts and Sciences.

While most readers of this Journal are familiar with some of

Dr. Shapley's numerous astronomical writings, from his early Princeton work on eclipsing binary orbits to his classical studies of star clusters, and his recent Harvard Monograph, *Galaxies,* fewer astronomers are aware of the fact that he has also contributed research papers in the fields of entomology and geology. On behalf of Dr. Shapley's wide circle of friends in this country, the editors of this Journal extend to him warmest congratulations on his award.

F. S. H.

MEETINGS OF THE SOCIETY

AT EDMONTON

December 14, 1944—The meeting was called to order by the President at 8.10.

The Treasurer's report was moved by Miss A. M. P. Smith and seconded by Mr. Blue, and carried. A small increase in our funds resulted from the year's operations.

A copy of the Librarian's report is attached to these minutes.

The Secretary read his report of the year's activities. The adoption was seconded by Mr. Wates and carried.

Mr. Wates gave a talk on the Handbook, mentioning the importance to everyone of the winter solstice. Venus is getting higher and brighter in the western sky during the evening, and Jupiter is a brilliant object in the morning sky. A total solar eclipse will be visible in Canada on July 9 next. Mr. Wates then read an amusing poem to Mira, the inconstant star.

The report of the nominating committee was read by the Secretary.

Dr. Campbell reported on the Observatory. There were some very large crowds which are not easy to handle, and an Observatory committee was suggested to study how best to make the telescope available to the public and to members who might wish to undertake some research requiring the telescope.

The main paper was given by Dr. J. M. MacEachran on "Cosmic Speculations Old and New." The Greek gods were personifications of natural and human powers, thought of as eternal in contrast with the mortality of individual humans. On this basis there should be no surprise when contradictory qualities are observed in the same god. The primordial substance is eternal, and hence of the nature of god. Pythagoras proposed a theory of mathematical forms of cosmic patterns. All laws summed in reason, the highest human faculty. Idealism, materialism, and creative evolution were compared.

Astronomy enlarges the human soul, and gives us a perspective on ourselves and our relation to the universe as a whole.

Modern philosophies are largely based on Plato, e.g. emergent evolution which considers deity as the next level ahead, more perfect than the present.

The meeting adjourned with a hearty round of applause at 10 p.m. There were 42 members and visitors present.

October 12, 1944—The vice-president called the meeting to order at 8.18 p.m.

The minutes of the previous meeting were read and approved.

Business arising: Dr. Campbell reported that the site chosen for the relocation of Mr. Wates' private observatory was just south of the present University Observatory, and the work will be done as soon as the materials and labour can be arranged.

New business: The audience paid a standing tribute to the memory of á past president, Mr. M. J. Hilton, who died suddenly during the summer. An outline of the summer courses organized by the Victoria and Montreal Centres was given.

On the motion of Mr. MacGregor and Mr. Blue, the following were elected to full membership in the Centre:

Mr. W. P. Sharp, 11923 55 St., Edmonton.

Mr. H. Dyksley, 11924 54 St., Edmonton.

The Librarian announced the gift from Mr. H. B. Collier of an extensive lunar atlas, which can be a valuable auxiliary to our model of the moon. He moved acceptance, and a hearty vote of thanks to Mr Collier. This was seconded by Mr. Blue and carried with a burst of applause.

It was moved by Mr. Wates, seconded by Dr. Revell, that the Executive consider the best use to which this gift can be put.

The Handbook talk was given by Dr. Campbell.

The main paper, "Changes in the Universe," was given by Mr. Wates. Man has always disliked change because it often means suffering. But beauty is dependent on change, say in sea and mountains.

Changes observed through an amateur's telescope help to keep up his interest. Some suggestions of permanent, not cyclical, changes open to amateur observation follow. Changes on the sun are easily observed with simple and easily constructed equipment. There are no changes on Mercury, but some may be seen on Venus. Changes on the moon's surface are very suitable, but those on Mars are very difficult to observe. Jupiter's satellites have a very large number of possible patterns, and his deep atmosphere has strangely permanent markings in cloud belts. Saturn's rings are not as simple as once thought. They may be changing fairly rapidly, the particles going from outer to inner rings, and finally to the surface of the planet. With Uranus we come to the limit of amateur observation.

Beyond the solar system there are comets, round at first, then developing a tail. Some amateur might see a comet divide or vanish. Stars change in brightness and become novae. Some show the rotation of a binary. Variable star observation is a very important part of the amateur contribution to Astronomy.

After some questions and discussion the meeting adjourned for refreshments at 9.40. There were 30 members and visitors present.

E. H. GOWAN, *Honorary Secretary.*

The Royal Astronomical Society of Canada

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